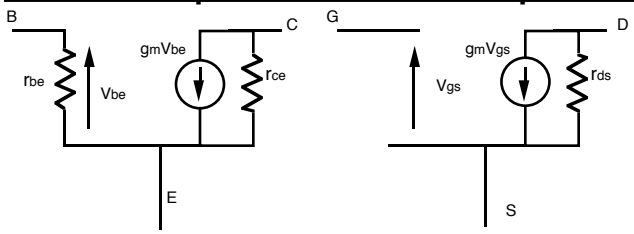
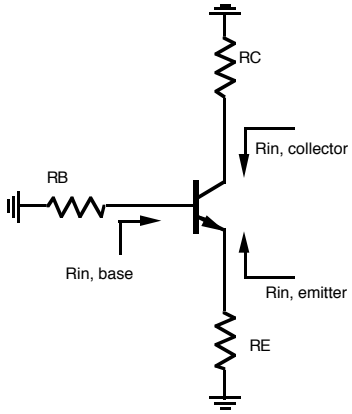
## Basics: Amplifiers at Low Frequencies




Left is the equivalent circuit of a bipolar transistor; $g_m=I_E/V_T=1/r_e$, $V_T=kT/q$, $r_{b'e}=ßr_e=ß/g_m$. On the right is the FET model. Below is a transistor with ac equivalent load resistances $R_c$, $R_E$, and $R_B$.

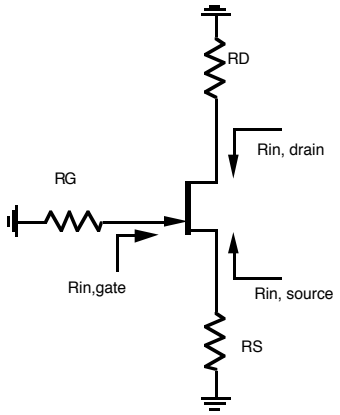



For the bipolar

$$R_{in,base} = (\beta+1)(R_E + r_e)$$

$$R_{in,emitter} = \left(r_e + \frac{R_B}{\beta+1}\right)\left(\frac{r_{ce}+R_C}{r_{ce}}\right) \cong \left(r_e + \frac{R_B}{\beta+1}\right),$$

$$R_{in,collector} = r_{ce}\left\{1 + g_m R_E\left(\frac{r_{b@}}{r_{b@} + R_E + R_B}\right)\right\} \cong r_{ce}\{1 + g_m R_E\}$$




For the fet: THE EQUATIONS ARE THE SAME IF ß is INFINITE!

$$R_{in,gate} = open$$

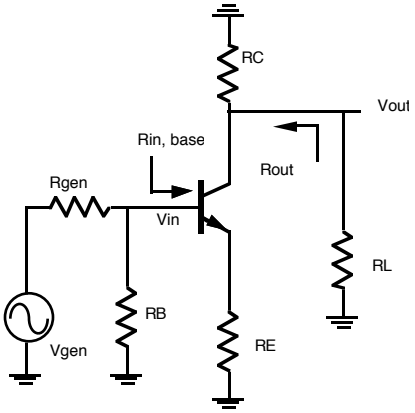
$$R_{in,source} = \left(\frac{1}{g_m}\right)\left(\frac{R_D + r_{ds}}{r_{ds}}\right) \cong \left(\frac{1}{g_m}\right)$$

$$R_{in,drain} = r_{ds}\{1 + g_m R_S\}$$

Be warned that in the equations above Rc, RE and RB are the equivalent resistances seen by the transistor. So in, the amplifier circuits below, THINK: "what is the effective resistance seen by the transistor?", before plugging into the equations.

## Amplifier Stages

Common Emitter and Common Source



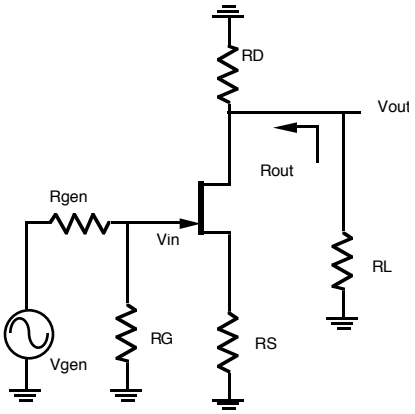

Common emitter:

$$R_{in} = R_B \| R_{in,base} = R_B \| (\beta + 1)(R_E + r_e)$$

$$\frac{V_{in}}{V_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{-(R_{Leq})}{r_e + R_E} = \frac{-(R_C \| R_L \| R_{out,collector})}{r_e + R_E}$$

$$R_{out} = (R_C \| R_{out,collector})$$




Common source:

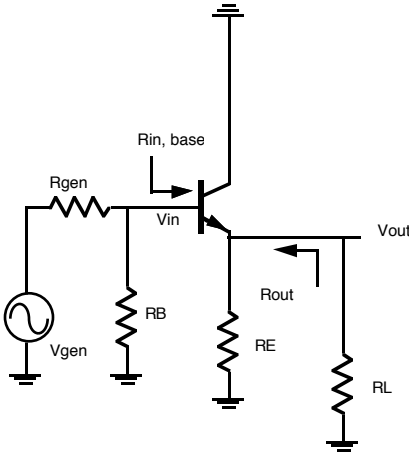
$$R_{in} = R_G$$

$$\frac{V_{in}}{V_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{-(R_{Leq})}{1/g_m + R_S} = \frac{-(R_D \| R_L \| R_{out,drain})}{1/g_m + R_S}$$

$$R_{out} = R_D \| R_{out,drain}$$

Common Collector (emitter follower) and common drain (source follower)



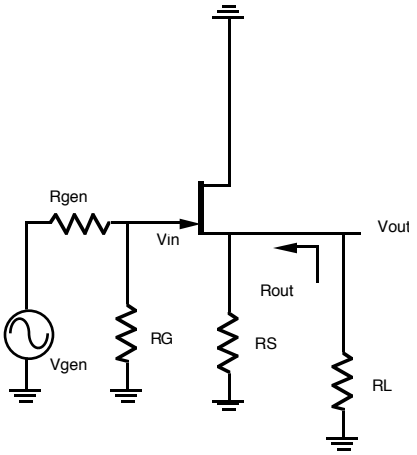

for the emitter follower:

$$R_{in} = R_B \| R_{in,base} = R_B \| (\beta + 1)(R_E \| R_L + r_e)$$

$$\frac{V_{in}}{V_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{R_{Leq}}{r_e + R_{Leq}} = \frac{R_E \| R_L}{r_e + R_E \| R_L}$$

$$R_{out} = R_E \| R_{in,emitter} = R_E \| \left( r_e + \frac{R_B}{\beta + 1} \right)$$




For the source follower:

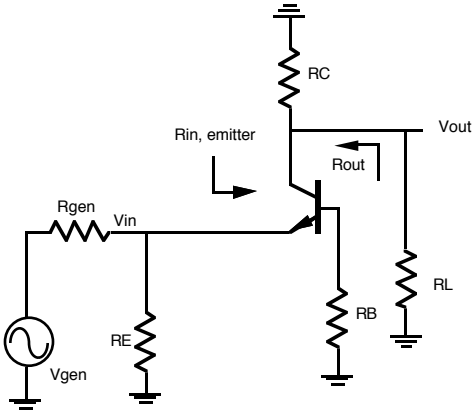
$$R_{in} = R_G$$

$$\frac{V_{in}}{V_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{R_{Leq}}{1/g_m + R_{Leq}} = \frac{R_S \| R_L}{1/g_m + R_S \| R_L}$$

$$R_{out} = R_S \| R_{in,source} = R_S \| \frac{1}{g_m}$$

Common Base and common gate




For the common base:

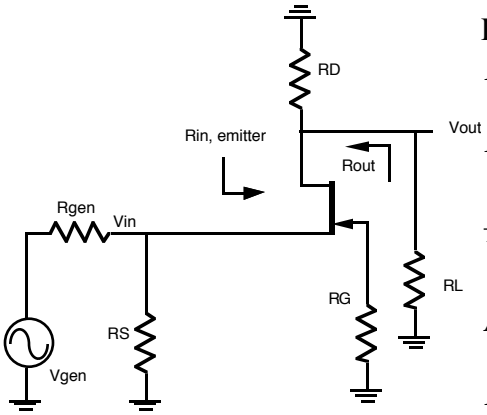
$$R_{in} = R_E \| R_{in,emitter}$$

$$R_{in,emitter} = \left( r_e + \frac{R_B}{\beta + 1} \right) \left( \frac{r_{ce} + R_C \| R_L}{r_{ce}} \right) \cong \left( r_e + \frac{R_B}{\beta + 1} \right)$$

$$\frac{V_{in}}{V_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{R_{L,eq}}{R_{in,emitter}} = \frac{R_C \| R_L}{R_{in,emitter}}$$

$$R_{out} = (R_C \| R_{out,collector})$$




For the common gate

$$R_{in} = R_S \| R_{in,Source}$$

$$R_{in,source} = \left( \frac{1}{g_m} \right) \left( \frac{R_D \| R_L + r_{ds}}{r_{ds}} \right) \cong \left( \frac{1}{g_m} \right)$$

$$\frac{V_{in}}{V_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{R_{L,eq}}{R_{in,source}} = \frac{R_D \| R_L}{R_{in,source}}$$

$$R_{out} = R_D \| R_{out,drain}$$